Solid state quantum computation

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Quantum Computation (QC) has recently excited many scientists from various different areas of physics. The increasing interest in this field is certainly related to the fact that some problems, which are intractable with classical algorithms, can be solved much faster with QC.

Factorization of large numbers, as proposed by Shor, is probably the most famous example of quantum algorithms. Large-scale integration is needed to make a quantum computer useful Qubits made out of solid-state devices may offer a great advantage in this respect because fabrication techniques allow for scalability to a large number of coupled qubits. Josephson qubits are among the most promising devices to implement solid-state quantum computation. Quantum manipulations of individual and coupled qubits have been demonstrated experimentally.

The interest in nanostructures for quantum information processing is not confined to the understanding of the implementation of quantum gates for quantum computation.

Very recently people have started to study how to generate and to manipulate entangled pairs in a solid-state environment. The reason for pursuing research in this direction is twofold. Besides the immediate impact in the field of quantum information, it has been recently realized that introducing concepts and methods developed in quantum information theory may bring a further understanding of condensed phases. Several proposals have been put forward with the aim of measuring non-local correlations in condensed matter systems. Josephson nanocircuits are one important example.

We showed that Josephson junction arrays can be used as quantum channels in order to transfer quantum information between distant sites.

The one-dimensional Josephson array proposed for the transmission of quantum states is showed in the figure 1. The crossed rectangles denote the Josephson junctions between the islands. The state prepared on the left-most island is transferred to the right-most island by the time evolution generated by the Hamiltonian. In the left part the Cooper-pair box (charge used to prepare the state. On the right the SET transistor used as measurement device.

Quantum communication is not the only protocol that can be realized using solid state devices. We analyzed in details how to implement quantum cloning using a network of spins interacting with a XY Hamiltonian and without any time-dependent control on the parameters of the Hamiltoniana. Such a system can be realized with a Josephson network.

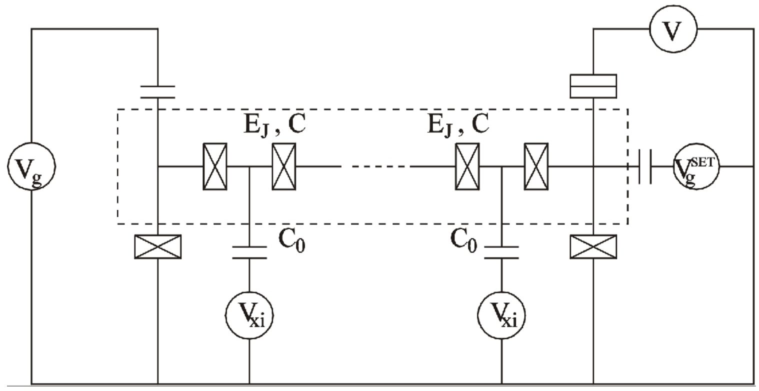

Fig. 1
The one-dimensional Josephson array proposed for the transmission of quantum states

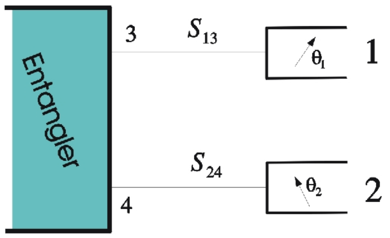

Fig. 2
Idealized setup for testing the CH inequality for electrons in a solid state environment. It consists of two parts: an entangler (shaded block) that produces pairs of spin entangled electrons exiting from terminals 3 and 4. These terminals are connected to leads 1and 2 through two conductors described by scattering matrices S_{13} and S_{24}. Electron counting is performed in leads 1and 2 along the local spin-quantization axis oriented at angles q_1 and q_2.

We have demonstrated that quantum cloning, in particular the phase covariant cloner, can be realized using no external control but just with an appropriate design of the system Hamiltonian. We found that the XY model, appropriate for Josephson nanocircuits, saturates the optimal value for the fidelity of the 1 --->2 of the phase covariant cloner. In all other cases we have analyzed our protocol gives a value of the fidelity of clones that is always within a few percent to the optimal value. As compared to the standard protocol using quantum gates, however, there is a major advantage.

Our setup is fast and, moreover, its execution time does not increase with the number of qubits to be cloned. In the presence of noise this allows to reach a much better fidelity than the standard protocol even in the presence of a weak coupling to the external environment. In addition we expect that the system in the protocol proposed by us is better isolated from the external environment because no gate pulses are needed.

The system proposed by us would be the first experimental realization of quantum cloning in solid state systems. We want to stress that our results on cloning together with others on communication and computation open new perspectives in the realization of a quantum processor, reducing the effect of noise on the system.

We would like to close this section on solid state quantum computation by mentioning the large interest in the study of entanglement in multiterminal mesoscopic devices. We have derived and discussed the Clauser-Horne (CH) inequality for the full counting electron statistics. In an idealized situation in which one supposes the existence of an *entangler* Fig. 2, we have found that the CH inequality is violated for joint probabilities relative to an equal number of electrons that have passed in different terminals. This is related to the intuition that any violation is lost in absence of coincidence measurements. The extent of the violation is suppressed for increasing M average number of injected pairs. The violation of the CH inequality could be achieved in an experiment. Indeed we tested the CH inequality for two different realistic systems, namely a normal beam splitter and a superconducting beam splitter. Interestingly we find a violation even for the normal system, even though weaker with respect to the idealized case of the entangler. Also in this case the violation is again suppressed for increasing observation time.

References

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